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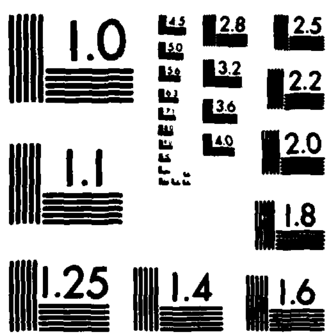
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An initial assessment of the 600-gallon-per-hour reverse osmosis water purification unit
Field water supply on the winter battlefield

J.R. Bouzoun, S.C. Reed and C.J. Diener

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An initial study was conducted to determine the effects of raw water temperature on the finished water production rates of the Army's new 600-gal./hr Reverse Osmosis Water Purification Unit (ROWPU). This study showed that the finished water production rates decreased from 687gal./hr at a raw water temperature of 68.3°F to 348 gal./hr at a raw water temperature of 33.7°F. The report also has a list of suggestions on how to set up and operate the ROWPU on the winter battlefield.

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PREFACE

This report was prepared by John R. Bouzoun and Sherwood C. Reed, Environmental Engineers, and Carl J. Diener, Civil Engineering Technician, all of the Civil Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this study was provided by DA project 4A762730AT42, *Design, Construction and Operations Technology for Cold Regions*, Task D, *Cold Regions Base Support; Design and Construction,* Work Unit 001, *Utility Services for Remote Military Operations and Facilities in Cold Regions*.

C. James Martel and Robert Sletten of CRREL technically reviewed the manuscript of this report.

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CONVERSION FACTORS: U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	By	To obtain
inches	25.4	millimetres
feet	0.3048	metres
square feet	0.09290304	square metres
pounds (mass)	0.4535924	kilograms
degrees Fahrenheit	$t°C = (t°F-32)/1.8$	degrees Celsius
pounds (force) per square inch	0.006894757	megapascals
gallons	0.003785412	cubic metres
gallons per minute	0.0000630902	cubic metres per second

An Initial Assessment of the 600-Gallon-per-Hour Reverse Osmosis Water Purification Unit
Field Water Supply on the Winter Battlefield

JOHN R. BOUZOUN, SHERWOOD C. REED AND CARL J. DIENER

INTRODUCTION

In June of 1979 the Army accepted (type-classified) the 600-gal./hr Reverse Osmosis Water Purification Unit (ROWPU). Since then the ROWPU has been procured for all the services of the Department of Defense. However, because of the urgent need for this type of equipment, the ROWPU was not tested at the Cold Regions Test Center (CRTC), Fort Greely, Alaska, before it was type-classified.

At the request of the Cold Research Division of the U.S. Army Research Institute of Environmental Medicine, Natick, Massachusetts, the operator's manual for the ROWPU (U.S. Army 1982) was reviewed by CRREL to determine if there would be any potential problems in operating the ROWPU on the winter battlefield. The review revealed two potential problems with the ROWPU. The first concern was with the water production rates when cold raw water sources were used. The second concern was with the shut down, transport and start up of the unit under winter conditions (Reed 1983).

Water production rates

The operator's manual states that "The ROWPU makes less product water when temperature of the raw water drops." This happens because of viscosity effects. Since surface waters in the northern temperate zone typically have a temperature of around 35 °F and surface waters in the arctic and subarctic typically have a temperature of around 32 °F during the winter, the water production rates of the ROWPU will be less than the rated 600 gal./hr.

Shut downs, transport and start ups

The operator's manual (U.S. Army 1982) has specific instructions on how to start up and shut down the ROWPU. These include draining the components to avoid freezing in the mechanical elements and plumbing. However, it is doubtful that the multimedia filter, the cartridge filter, and the reverse osmosis elements will drain sufficiently to protect them from freezing during transport. The manual recognizes the potential for freezing problems with the reverse osmosis elements and instructs the operator: "When the ROWPU is shut down during cold weather (temperature falls below 32 °F (0 °C), remove the R.O. elements... Store the elements indoors." These instructions are applicable to the shut down of the ROWPU in preparation for transportation, but not for the transportation itself. During transportation the only warm space available will most likely be the cab of the towing vehicle. Even if space is available in the cab of the vehicle, the membranes in the RO elements may be damaged or contaminated.

Purpose

This report will give the results of CRREL's initial assessment of the operational characteristics of the 600-gal./hr ROWPU on the winter battlefield. Specific information will be given on production rates as a function of raw water temperature. Also, suggestions

on setting up and operating the ROWPU will be presented, and additional research needs will be identified.

DESCRIPTION

The ROWPU is a trailer-mounted mobile water purification unit. Power for the unit is supplied by a 30-kW diesel generator. Table 1 gives the weight, dimensions, and power requirements of the ROWPU.

The ROWPU has three water treatment steps, in sequence, that remove the suspended and dissolved solids from the raw water. They are the multimedia filter, the cartridge filter, and the reverse osmosis pressure vessels.

The multimedia filter consists of six layers of synthetic pellets, anthracite, sand and gravel contained in a steel tank. A polymer is added to the raw water to cause small suspended particles to flocculate together into larger particles, and the multimedia filter removes these larger particles. The multimedia filter is backwashed when the multimedia gauge rises 5 $lb/in.^2$ above the reading at start up, or after 20 hours of operation, or whenever the ROWPU is to be shut down for an extended period. Once the operator sets the backwash timer and the backwash valve and starts the backwash cycle by turning on the backwash switch, a timer mechanism, in conjunction with a backwash diaphragm valve, automatically controls the backwashing of the multimedia filter.

The cartridge filter consists of eight woven polypropylene filters with 5-μm openings. The cartridge filter removes the very small particles that are left in the water coming from the multimedia filter. The cartridge filter tube elements are replaced when the cartridge filter pressure gauge differential rises above 20 $lb/in.^2$.

There are four reverse osmosis pressure vessels, each with two spiral wound polyether–urea reverse osmosis elements. Each element is 6 in. in diameter and 40 in. long, and has 159 ft^2 of surface area, giving a total of 1272 ft^2 of surface area.

Table 1. ROWPU weights, dimensions and power requirements.

Weights:			
	Skid-mounted ROWPU section		7300 lb
	30-kW diesel generator		2850 lb
	Trailer		6625 lb
		Total	16975 lb
Dimensions:			
	Skid-mounted ROWPU section		
		length	9 ft,6 in.
		width	6 ft, 11 in.
		height	5 ft ,7 in.
	Total unit		
		length	19 ft, 2 in.
		width	8 ft, 0 in.
		height	8 ft,1 in.
Power requirements:			
	Power		22 kW
	Voltage		208/120 Vac
	Phase		3
	Hertz		60
	Current		104 A (max)

The reverse osmosis elements are cleaned by flushing them with a citric acid solution when the reverse osmosis pressure rises above 800 lb/in.^{2} for seawater or 500 lb/in.^{2} for fresh water, or when the product water flow decreases several gallons per minute, or when the brine flow increases noticeably.

EXPERIMENTAL PROCEDURE

A ROWPU was set up in the basement of the CRREL Ice Engineering Facility and the rate of water production was measured at seven raw water temperatures. The raw water, which contained urea (less than 1000 mg/L total dissolved solids), was normally used for model studies in the Ice Engineering Facility. This water was held in a storage tank and could be chilled by circulating it through a refrigeration unit. The ROWPU was set up and operated in accordance with the operator's manual (US Army 1982) during each experimental run.

Each experimental run was 60 minutes long from the time the product water began to flow into its storage tank.

The volume of water produced during each run was determined by measuring the depth of the water in the storage tank at the end of each run and calculating its volume.

The temperature of the raw water was measured by a thermocouple attached to the end of the raw water supply hose, which was submerged in the water storage tank. A data logger read and recorded this thermocouple reading every 10 minutes during each experimental run. Another thermocouple measured the ambient air temperature during the experimental runs.

The total dissolved solids (TDS) concentration of the raw water, the product water and the brine was measured with the TDS meter provided with the ROWPU.

In order to maintain the same operating conditions during each experimental run, the pressure in the reverse osmosis pressure vessels was adjusted to 500 lb/in. by increasing or decreasing the product water flow rate. Once this reverse osmosis operating pressure was set at the beginning of each run it remained relatively constant during each experimental run.

RESULTS AND DISCUSSION

Table 2 gives the ambient air and raw water temperatures, and the water quality and quantity data during each experimental run. Figure 1 is a plot of the measured water production rates as a function of raw water temperature as given in Table 2.

To determine the relationship between the production rate and the raw water temperature, we did a linear regression analysis of the natural logarithm of flow rate versus the raw water temperature, giving the following equation:

$$Q = 188.3 \exp. 0.019T \quad r = 0.98 \qquad (1)$$

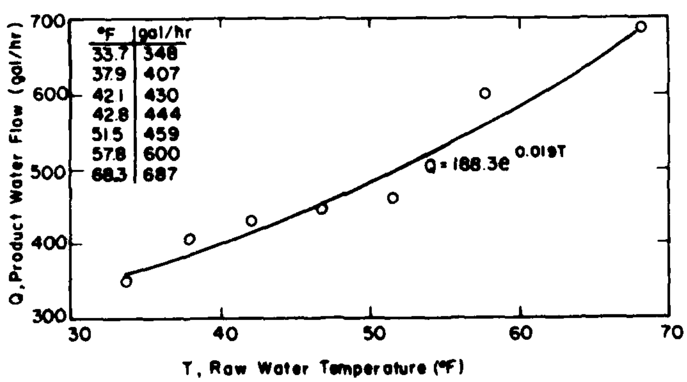

Figure 1. Water production versus temperature.

Table 2. Water quality and quantity data.

Run	Average air temp (°F)	Average raw water temp (°F)	Raw water flow (gal./min)*	Brine flow (gal./min)*	Product water flow (gal./min)*	Measured product water flow (gal./hr)**	Raw water TDS (mg/L)	Brine TDS (mg/L)	Product water TDS (mg/L)
1	66.1	57.8	29	15	12	600	800	1400	53
2	67.0	46.8	29	17	09	444	900	1300	43
3	66.5	42.1	28	19	08	430	800	1200	41
4	67.0	33.7	28	20	07	348	800	1100	42
5	66.6	37.9	28	—	—	407	800	1100	43
6	63.3	51.5	35	23	11	459	800	1200	47
7	60.0	68.3	35	18	16	687	900	1600	60

* These data were taken from the gauges on the control panel.
** These data were calculated from the depth of water in the storage tank.

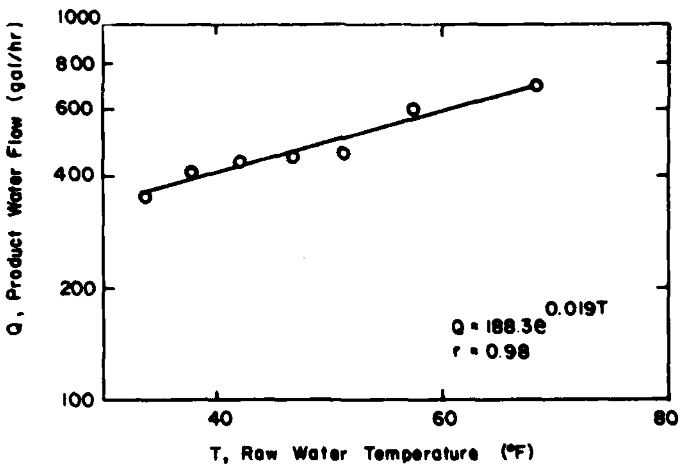

Figure 2. Plot of data and line of best fit.

where Q is product water flow (gal./hr), and T is raw water temperature (°F).

The high correlation coefficient, $r = 0.98$, indicates that there is a high positive correlation between product water flow rate and raw water temperature. Additional statistical analysis also showed that the correlation coefficient was highly significant at the 99% confidence level. A plot of the data and the line of best fit are shown in Figure 2.

The viscosity of water is a measure of its resistance to shear. The friction forces in fluid flow result from the cohesion and momentum interchange between molecules in the fluid. In water the force of cohesion increases as temperature decreases. This makes it more difficult for the water to pass through the reverse osmosis membranes. This explains the decrease in production rate at the lower temperatures as seen in this experiment.

Nusbaum and Riedinger (1978) give the following equations to describe the flow of water and salt across the the membrane in reverse osmosis systems:

$$F_w = A(\Delta P - \Delta\pi) \quad (2)$$

and

$$F_s = B(\Delta C) \quad (3)$$

where

F_w = water flux
A = water transport coefficient
ΔP = pressure differential across the membrane
$\Delta\pi$ = osmotic pressure differential across the membrane
F_s = salt flux across the membrane
B = salt transport coefficient
ΔC = salt concentration gradient across the membrane.

Both the water transport coefficient, A, and the salt transport coefficient, B, decrease with decreasing water temperature. Because both the water and salt flux rates are directly proportional to their respective transport coefficients, any decrease in temperature results in a reduction in these flux rates.

CONCLUSIONS

The decline in production rate with lower raw water temperatures was not unexpected. This study, however, was the first one conducted to actually quantify this decrease. As previously stated, it was intended to be only a very preliminary study, and, as such, it has confirmed what was expected.

Setting up and operating the ROWPU on the winter battlefield

Based on our previous experience with water supply point operations on the winter battlefield and on the experience we gained with the ROWPU during this study, the following are suggestions on how to set up and operate the ROWPU on the winter battlefield:

1. The ROWPU must be set up in a heated maintenance tent or shelter. A maintenance tent is required because the height of the ROWPU (8 ft., 1 in.) prohibits the use of any of the general purpose (GP) tents in the Army inventory.

2. The steel frame of the maintenance tent should be elevated off the ground by placing it on boards or logs so that it will not freeze to the ground.

3. The ground inside the maintenance tent should be cleared of snow, and pallets or other materials placed on it to provide a dry, mudfree and level surface for walkways, storage and to serve as a foundation for the product water storage tanks and for the brine tank.

4. The maintenance tent must be heated to maintain the temperature above freezing. At least one backup heater must be on hand and in operational condition at all times.

5. The exhaust from the diesel generator must be vented to the outside at all times.

6. Ear protection must be available and worn by all personnel in the tent whenever the ROWPU is being operated.

7. Extreme care should be taken to avoid spills when dispensing water into water trailers, tankers and cans. Any spilled water will form sheets of ice that can cause vehicles to lose traction and personnel to lose their footing. Sand or wood ashes should be spread on any ice that forms.

8. The product water distribution hose and nozzle should be placed inside the tent after they are used to keep them from freezing.

9. All drain valves on the ROWPU should have tubing placed on them to carry all drainage to a container. The drainage water should not be allowed to drain onto the ground inside the tent because it will increase the amount of mud inside, and if it flows to the outside of the tent it will freeze.

10. Cribbings of timbers should be placed under each of the four leveling jacks on the ROWPU trailer to keep them from sinking into the ground as the soil inside the warm tent thaws.

11. If the distance from the ROWPU to the raw water supply requires that one or both of the raw water pumps be placed outside of the tent it is absolutely essential that these pumps and hoses be brought inside the tent and drained after each use. If they are not completely drained they will freeze during the time that they are being hooked up and primed.

12. If the vent vessel and the waste waters are being discharged onto the ground in accordance with the operator's manual, extreme care should be taken to select a location that will not cause an ice safety hazard to personnel and equipment. In extreme cold much of this water will freeze on the surface and not infilitrate into the ground.

13. If camouflage nets are used, particular care should be taken to prevent their freezing to the ground or into any ice that forms as a result of spills.

Additional research needs

There are other important questions concerning the operation of the ROWPU on the winter battlefield that must be answered to provide military planners and commanders with concise information upon which to base their plans and decisions.

The effects of high sediment concentrations in the raw water on the operation of the ROWPU must be determined. Many streams in the arctic and the subarctic, particularly those that are glacial fed, have extremely high concentrations of suspended sediments in them. These sediments must be removed by the multimedia and cartridge filters or they will rapidly clog the reverse osmosis elements. The higher the suspended sediment concentration in the raw water is, the more frequently the multimedia filter will have to be backwashed and the more frequently the cartridge filters will have to be replaced. Experiments using different raw water sources with different suspended sediment concentrations must be conducted to determine both the production rates as a function of sediment concentration and the amount of time the filters can operate before they have to be backwashed.

The operational characteristics of the ROWPU when cold seawater is used as the raw water source must be determined. The high dissolved solids content of seawater (approximately 35,000 mg/L) depresses its freezing point to about 27°F. As this 27°F seawater passes through the reverse osmosis elements and the dissolved solids are removed the product water may freeze in the reverse osmosis elements. Tests should be conducted to determine whether or not this occurs.

Based on the results of this study, which have demonstrated the viscosity effects of cold raw water on the production rate of the ROWPU, methods of preheating the raw water should be investigated. Two methods that are most applicable are preheating the raw water with immersion heaters or the waste heat from the diesel generator exhaust. Studies should be conducted to determine the most effective way of implementing both of these methods.

Studies should also be conducted to determine if there will be any freezing problems during transportation of the ROWPU in winter. If problems are encountered, methods of alleviating them should also be developed.

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